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WAWAITIN GS
WEST DYKE REHABILITATION - ROLLER COMPACTED CONCRETE

Report No 88-40-K

P.K. Mukherjee/G.M. Kidd

ABSTRACT

Ontario Hydro is considering the use of Roller Compacted Concrete (RCC) construction for the proposed rehabilitation work of the Wawaitin GS control dam near Timmins, Ontario. Preliminary testing of materials and concrete specimens made from RCC mixtures was carried out in the Research Division laboratory. On the basis of the excellent results from this testing, it was decided that a trial RCC strip be made at the Dufferin Construction Co. yard at the Pearson International Airport. This concrete strip is presently being sampled and further testing has been recommended.

job	file	date	report no.
42-105-475	842.3WAWA	May 30, 1988	88-40-K

TABLE OF CONTENT

		Page
1.0	INTRODUCTION	1
2.0	LABORATORY EVALUATION	1
	2.1 Method of Compaction of Cylinders	2
3.0	TRIAL STRIP	2
	3.1 Observations	2
	3.2 Aggregates from the Dufferin Yard Stockpile	2
	3.3 Mix Proportion	2
	3.4 Trial Strip	3
	3.5 Mixing Equipment and Procedure	3
	3.6 Transportation	4
	3.7 Spreading	4
	3.8 Consolidation	4
	3.9 Density Tests	5
	3.10 Compressive Strength	5
4.0	FUTURE TEST PROGRAM	5
5.0	ACKNOWLEDGEMENTS	6
FIGURES 1 TO 13		7
APPENDICES A TO G		15
DISTRIBUTION		Last Page

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To Mr. O. Bernaus
Civil Works Department
A12H18

Attn: Mr. R.T. Judek

WAWAITIN GS
WEST DYKE REHABILITATION - ROLLER COMPACTED CONCRETE

1.0 INTRODUCTION

This is a preliminary review of Roller Compacted Concrete (RCC) system proposed for the rehabilitation of the Wawaitin GS control dam near Timmins, Ontario. Samples of aggregates suitable for RCC were obtained from Timmins area. These aggregates were used in the laboratory trial tests in order to determine the properties of the fresh and hardened concrete[1]. On the basis of the excellent results from this testing, it was decided to lay a trial RCC strip at the Dufferin Construction Co. yard at the Pearson International Airport using locally available materials. This report gives details of the field trial and related laboratory tests carried out on the RCC.

2.0 LABORATORY EVALUATION

During a preliminary investigation of the Wawaitin GS dam, granular 'A' and HL3 aggregates obtained from several pits in the Timmins area were checked in the Research Division laboratory. The granular 'A' aggregate was selected as the only aggregate to be used in the RCC mixtures. However, if an adjustment to the grading is required, a blend of HL3 aggregate could be used to keep the composite grading within the RCC aggregate grading limits (Figure 1).

A summary of the laboratory test data is given in Appendix A. All trial mixes were made in a drum mixer. The mixer provided an opportunity to observe the concrete while mixing. This helped in establishing the minimum time required to produce a well blended mixture suitable for RCC.

The concrete specimens were compacted in a special cylinder compaction mechanism with a double mould (Figure 2) that was built to withstand the consolidation force on the dry concrete mixture. The compaction procedure is described in Section 2.1. Excellent specimens were produced and very good test results were obtained (Appendix A). The densities of the RCC specimens were higher than those expected and well above the lower limit of 2350 kg/m^3 (141 lb/ft^3). Some specimens are still being stored for future testing.

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1. Wawaitin Dam Roller Compacted Concrete (Progress Report), Memo to Mr. R.T. Judek from Mr. P.K. Mukherjee (File: 842.3WAWA). August 17, 1987.

2.1 Method of Compaction of Cylinders

Each mixture was sampled and the cylinder mould (150 mm dia x 300 mm long) was over filled 1/3 the height before vibratory compaction was applied for 20 seconds. After the second 1/3 was compacted, an extension to the mould was added to hold the amount of sample mixture for the last 1/3. All concrete cylinder specimens were demoulded after 24 hours and cured in the fog room at 23°C and 100% relative humidity. The densities of these specimens were obtained by weighing in air and then in water.

3.0 TRIAL STRIP

3.1 Observations

In order to determine that the proposed RCC mixture could be placed under field conditions and that the resultant concrete would meet the requirements for dam construction, a trial strip was placed in the yard of Dufferin Construction Co. at the Pearson International Airport on October 29, 1987. The layout and the method of consolidation are described in the schematic diagram attached in Appendix B.

Although Dufferin Construction Co. had a batching system that used volume-measuring facilities and a pug-mill mixer (a system used for large volume production on dams), it was decided to use a pre-mix "Johnson" ready mix concrete plant (Figures 3 and 4) that batched all materials by weight (an exception was the fly ash that was batched by the bag - weighing 30 kg). The accuracy of the ready mix plant and the availability of the system for proportioning of each ingredient made this plant preferable for the trial strip. Testing of three classes of RCC mixtures placed under different degrees of consolidation with a 8-3/4 or 6 ton roller was carried out to obtain data on the properties of the concrete. The tests are being carried out both on laboratory-cured cylinders and field-cured specimens cored from the strip.

3.2 Aggregates from the Dufferin Yard Stockpile

The aggregates used in the Dufferin yard trial were tested in the field laboratory, as well as in the Research Division laboratory. Because of time constraint, only limited tests could be performed (Appendix C). The quality of aggregate was not the best; however, it was acceptable for the purpose of demonstration of RCC field procedure. The aggregates meet the requirements of granular 'A' gradation (MTC-Form 1010); however, some fractions were marginally outside the recommended gradation curve (Figure 1).

3.3 Mix Proportion

The following mix proportions were selected for the trial strip. The selection was based on the preliminary results of the laboratory evaluation tests carried out using the materials from Timmins area as reported earlier. Although, the materials used in the trial strip were from a different source, the properties of the freshly mixed RCC were expected to be about the same as those of the laboratory made concrete.

MIX PROPORTIONS (kg/m^3)

Materials	Mix 1	Mix 2	Mix 3
Cement Type 10	250	200	100
Fly ash Type F	-	-	100
Granular 'A'	2050	2100	2100
Water	100	110	100

After adjustments were made for moisture in the aggregates and minor variations in the batching plant weighing mechanism, the actual proportions were as follows:

ACTUAL MIX PROPORTIONS (kg/m^3)
(Average of 8 batches)

Material	Mix F-1	Mix F-2	Mix F-3
Cement Type 10	220	202	99
Fly ash Type F	-	-	99
Granular 'A'	2058	2057	1940
Water	144	139	135
Average cement factor Calculated from the yield	218	204	104

3.4 Trial Strip

A sketch of the layout of the trial strip sections (identified as Pads 1, 2 and 3) is shown in Appendix B. In preparation for the RCC test the trial strip area was excavated to an approximate depth of 0.75 m (2-1/2') and consolidated by an 8-3/4 ton roller before the test pad for each RCC mixture was placed, graded and rolled (Figure 5).

On the first day, October 29, two 300 mm (12") thick lifts were placed on Pad 1 only. The first lift of Mixes F-1, F-2 and F-3 was placed and consolidated before the second lift was placed on it. Similarly, on the following day, October 30, two 200 mm (8") lifts of the three mixes were placed on Pads 2 and 3. Also, a third lift of 200 mm (8") was placed on Pad 1. The width of this lift was somewhat less than that shown in the sketch. A sand-cement grout of stiff consistency was placed on the second lift of Pad 1 before placing the third lift. The mix proportions of the grout and its strength are included in Appendix G.

3.5 Mixing Equipment and Procedure

The "Johnson" portable batching plant (Figure 3) has a "low-boy" or horizontal configuration. That is, the aggregate holding bins, weighing bins and cement silo are in the same common structure as the belt conveyor. This structure can be detached, mounted on a truck-trailer and when required could be hauled to another site. At the upper end of the conveyor belt, a 7.7 m^3 (10 yd^3) mixer is mounted on a separate structure (Figure 4) and is fed from the

conveyor by a short chute. The three aggregate receiving bins are positioned about 10 m (30 ft) away in a line parallel to the conveyor. These bins are fed by separate conveyors.

A remote batching console is housed in a small building near the receiving bins. This console is computer controlled and backed with a semi-automatic manual control console. Light emitting diode (LED) figures show the weights in pounds of each material batched, ie, cement, aggregate and water. For the fly ash (FA) mixture, the 30-kg bags were hoisted by a front-end loader to the back of the aggregate bin where each bag was opened and dumped on a bed of aggregate. This helped in minimizing dust blowing from the conveyor belt while feeding the mixer. An improvement of the FA batching system is recommended.

The consistency of these mixtures is very dry and cannot be measured by the conventional methods such as slump cone or VeeBee test equipment. However, when the concrete samples are placed in the cylinder casting apparatus (described earlier), a small amount of mortar squeezes past the steel tamper head when the correct amount of moisture is present in the mix. Also, the paving roller produced a flat smooth finished surface indicating that the mixture had the correct moisture (too wet a mixture will push up in front of the roller).

3.6 Transportation

The mixer readily discharged the RCC mixtures into highway dump trucks and the mixture could easily be dumped out of the trucks with no sticking (Figure 6). The load of RCC was dumped in one pile or in two or three drops without any apparent detrimental effect on the spreading of the mixture.

3.7 Spreading

A standard road grader (Figure 7), with a 4.9 m (16 ft) blade, spread the mixture very easily and produced the required lift height without having to make many passes. However, for this trial the area was very confined for the movement of the grader. It has been reported that a grader, adapted from an asphalt spreader, places a very uniform lift. This type of equipment has been used elsewhere for RCC pavement placing and should be investigated for use in Ontario Hydro projects.

3.8 Consolidation

Two types of consolidation were used for this trial - a 8-3/4 ton and a 6 ton roller (Figure 8 to 10). By using a vibratory roller, approximately twice the force is produced over that of a static roller. Combination of static and vibratory rolling was used to produce maximum density. The effect of each pass of the roller was monitored by a Troxler density gauge. The results of these density tests and data on number of passes made with different types of rollers are attached in Appendix D.

3.9 Density Tests

The density of the RCC mixture was determined by the Troxler gauge tests (Figure 9). The results of these tests will be compared with those of the cored specimens taken from the same area and a correction factor can be developed for future field projects. The proctor density tests were also made and the results helped in controlling the mixture and moisture content (Appendix E).

Another test for control was the dry-out test. A known weight of a sample mixture was dried in a laboratory oven to determine accurately the total moisture, which provided an indirect check on the density.

3.10 Compressive Strength

The RCC specimens were made in 150 x 300 mm (6" x 12") cylinder moulds as described in Section 2.1. The concrete cylinders made from the RCC mixture were transported, after a maximum of 4 days of field laboratory curing, to the Research Division laboratory where they received a standard laboratory curing (23°C and 100% R/H) until tested. The compressive strength tests and tests for density and ultrasonic pulse velocity are presently being carried out. See Appendix F for results to date.

4.0 FUTURE TEST PROGRAM

To obtain long-term strength results, some of the cylinder specimens will be tested at 3 months and 1 year. However, the actual in-place concrete strength will be determined on 150 mm dia. (6" ϕ) cores. Some of these cores have been drilled from the trial strip in December 1987 (Figures 11 to 13). Further coring is planned in early spring of 1988. The cores that have been already drilled show good consolidation and bonding between the lifts at joints. The permeability tests on the cored specimens will also be performed.

5.0 ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions made by Messrs. W. Ng and B. Laffan of the Civil Works Department in reviewing this report and Mr. M.F. Everitt for carrying out some of the field observations.

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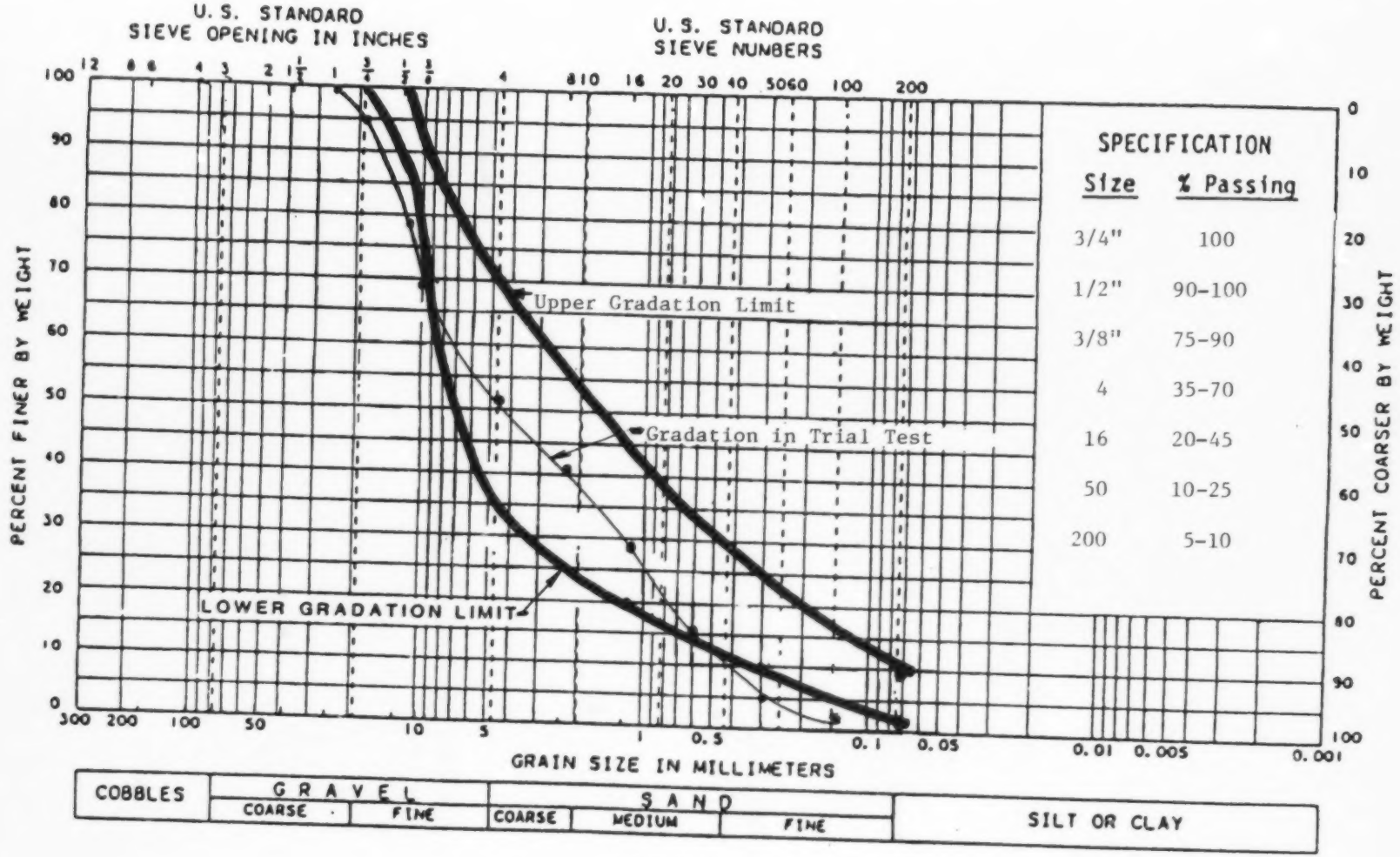


FIGURE 1

AGGREGATES GRADATION CURVE FOR RCC PAVEMENT

Figure 2

Special RCC Compaction System and Mould

Figure 3 - Johnson Pre-Mix Portable Ready Mix Concrete Plant.

Figure 4 - Mixing of the RCC mixture and the dump truck backing into place to receive the mixture.

Figure 5 - Prepared area before placing of RCC at Dufferin Yard.

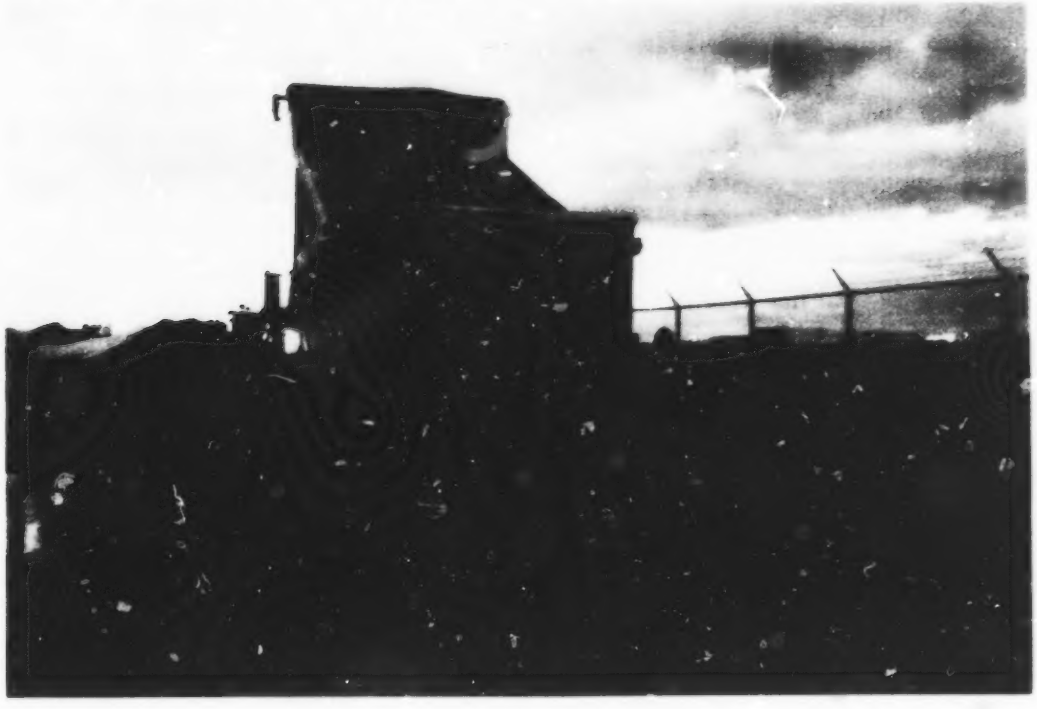


Figure 6 - Dumping of RCC mixture on the first pad.

Figure 7 - Spreading the RCC mixture with a grader.

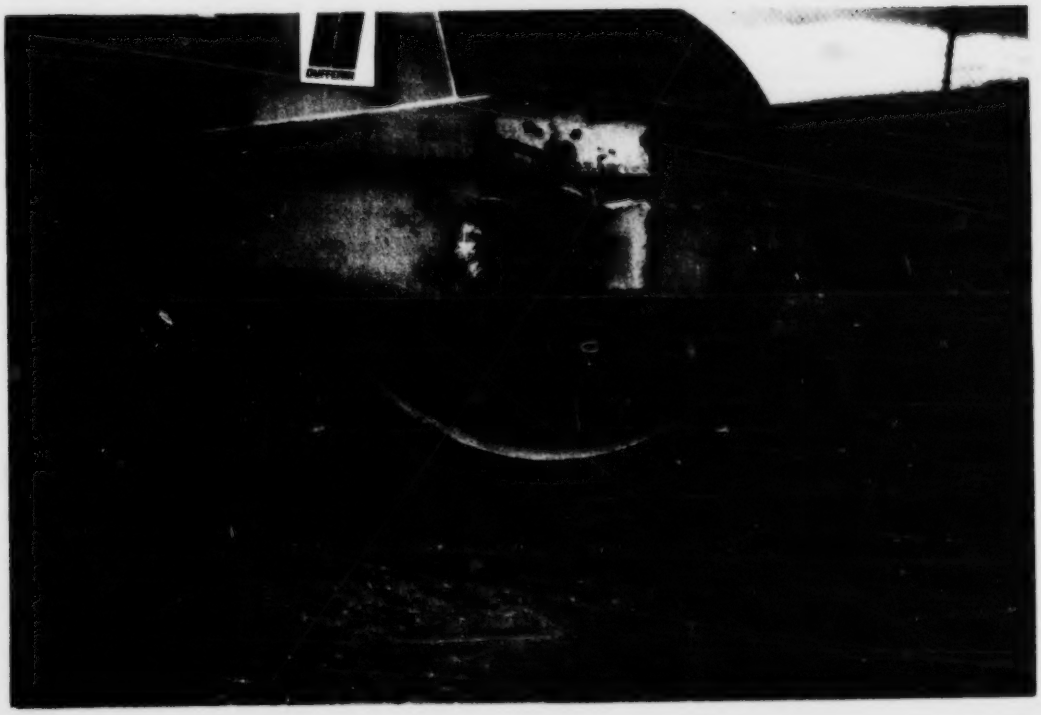


Figure 8 - 8-3/4 ton roller, compacting the RCC mixture.

Figure 9 - Testing for density and moisture by Troxler gauge after consolidation of RCC mixture.

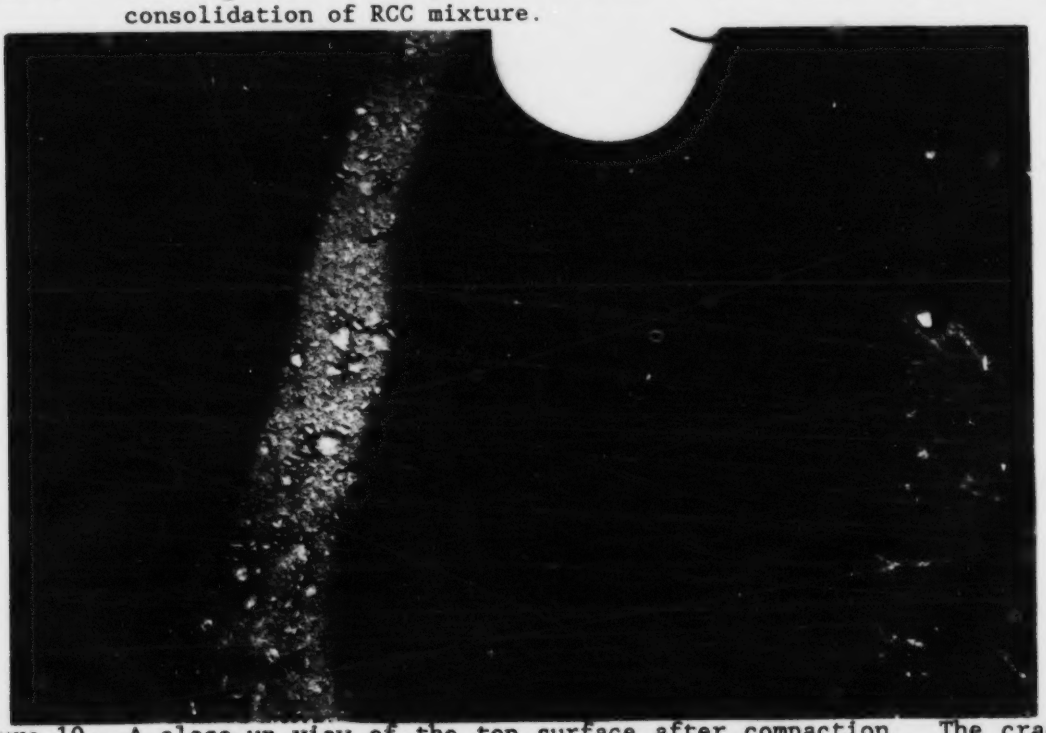


Figure 10 - A close-up view of the top surface after compaction. The cracks are confined to the surface only as confirmed later by coring.

Figure 11 - The trial pad is being drilled for obtaining core specimens.

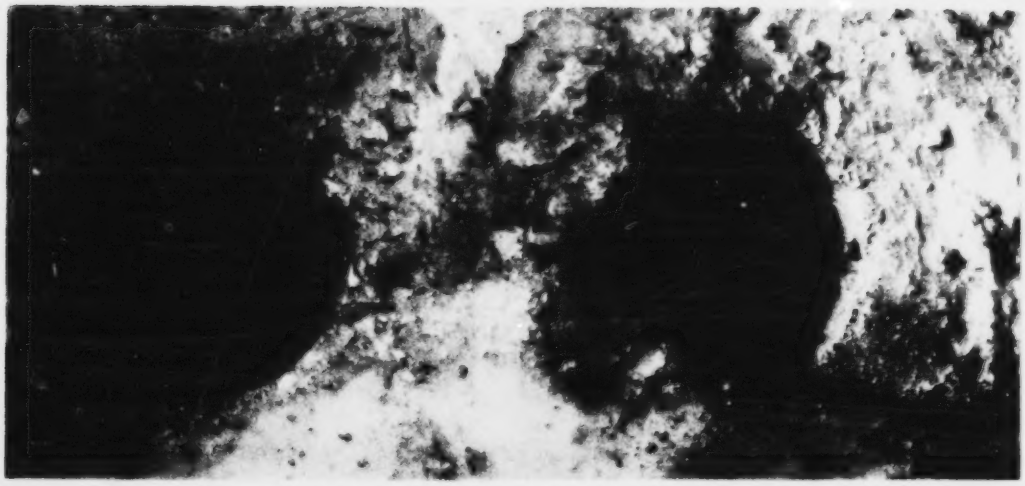


Figure 12 - Condition of the drilled holes after the cores are removed.

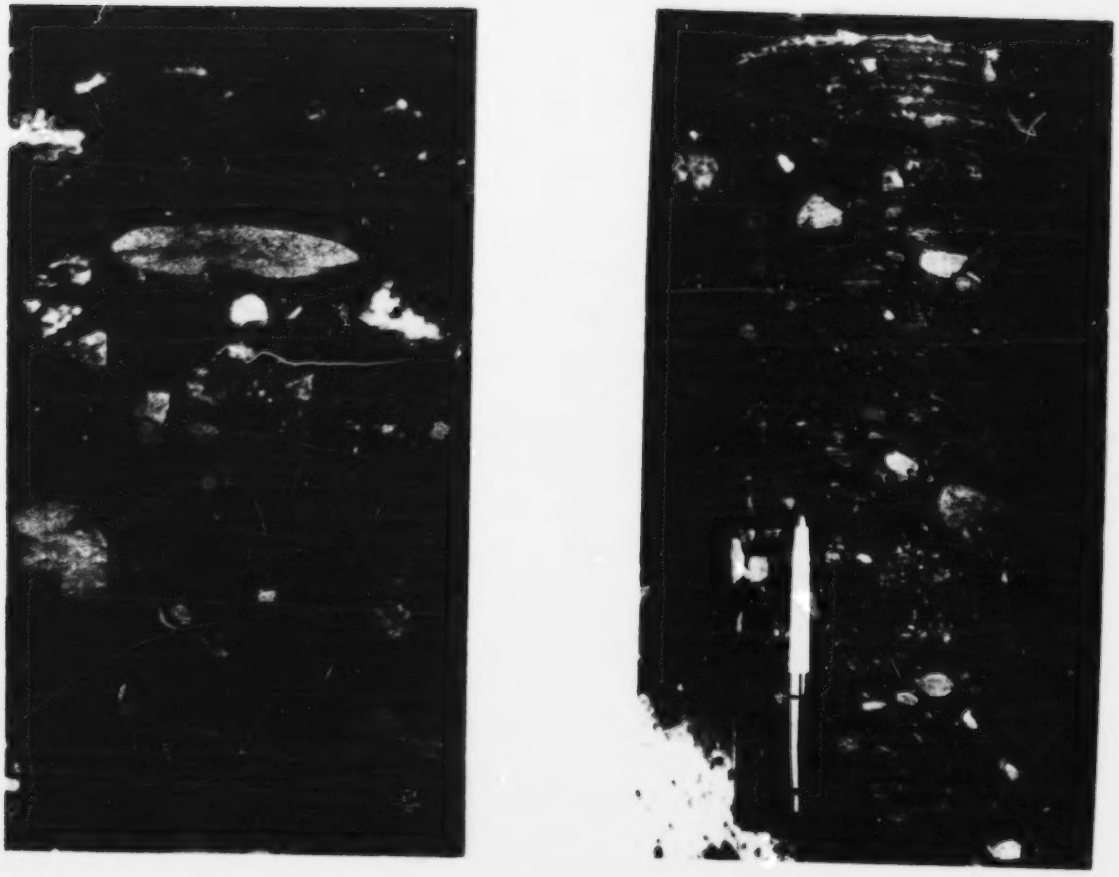


Figure 13 - Condition of the cores after removal. Note the good compaction of the concrete.

APPENDIX A

SUMMARY OF LABORATORY TEST PROGRAM

1. Materials:
   - cement - Type 10 - CL70180
   - fly ash - Class F CL68358
   - Granular "A" from Miller Paving, Timmins

2. Mix Proportions:

Material	Mix (kg/m^3)			
	L-1	L-2	L-3	L-4
Cement, Type 10	250 (10.6)*	150 (6.4)	100 (4.2)	60 (2.6)
Fly Ash, Class F	--	--	150 (6.4)	90 (3.8)
Granular "A"	2050 (87.1)	2150 (91.3)	2050 (87.1)	2150 (91.3)
Water (approx.)	110 (4.7) [6.15]	110 (4.7) [4.7]	100 (4.2) [5.75]	100 (4.2) [5.1]

* values in brackets are for 0.04 m^3 (1-1/2 ft^3) batches in kg.

Note: values in square brackets are actual amounts of water.

3. Mix Procedure:

   - Mixed dry ingredients for 15 sec.
   - Water added slowly until desired consistency achieved, 5-7 min.

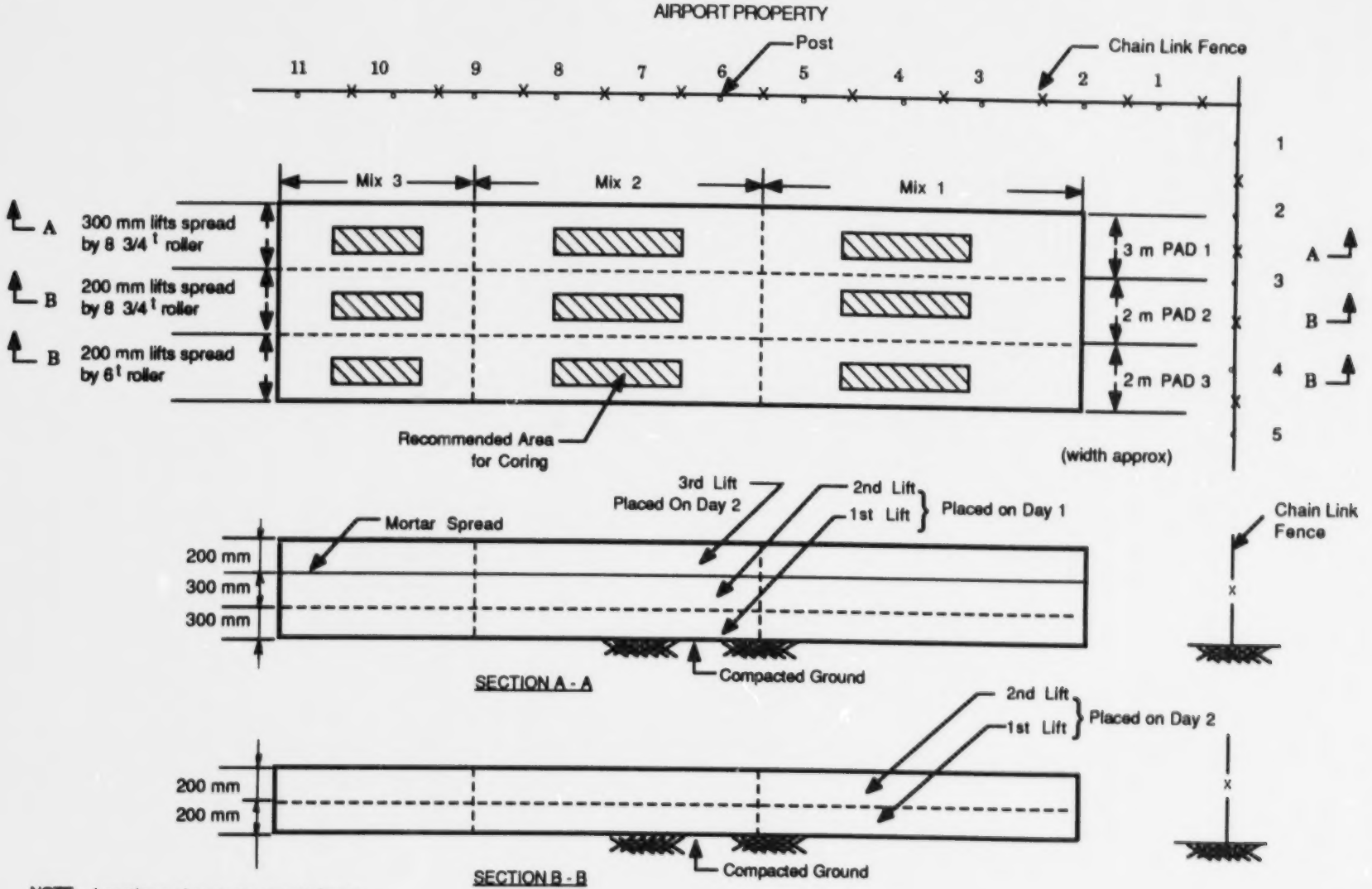
4. Compressive Strength and Density of Cylinders 150 x 300 mm (6" x 12"):

   - compacted in 3 layers using modified hammer and steel tamper; 20 sec per layer.
   - 7 cylinders/mix: 7(1), 28(2), 91(1), and 356(2) day compressive strength tests and (1) cylinder for permeability.

5. Results of Tests on Cylinders:

Mix	Serial/ Specimen No.	Date Cast	Density (kg/m^3)	Compressive Strength		
				Age (Days)	PSI	MPa
L-1	13859-1	Sept. 24/	2449	7	2865	19.8
	-2	1987	2470	28	3645	25.1
	-3		2461	28	3555	24.5
	-4		2474	91	4395	30.3
	-5		2477	365		
	-6		2472	365		
	-7		2465	For permeability test		
L-2	13860-1	Sept. 24/	2361	7	955	6.6
	-2	1987	2404	28	1946	13.4
	-3		2434	28	2140	14.8
	-4		2423	91	2610	18.0
	-5		2429	365		
	-6		2420	365		
	-7		2420	For permeability test		
L-3(*)	13862-1	Oct. 1/	2400	28	1981	13.7
	-2	1987	2392	91	1981	13.7
	-3		2360	180		
	-4		2368	For permeability test		
L-4	13863-1	Oct. 6/	2428	7	630	4.3
	-2	1987	2475	28	1170	8.1
	-3		2471	28	1130	7.8
	-4		2471	91	1925	13.3
	-5		2469	365		
	-6		2466	365		
	-7		2491	For permeability test		

(*) Because of the compaction equipment failure, the number of specimens that could be made were not enough for all the tests as scheduled.



NOTE: Locations shown are approximate. Reference to the post numbers should be made in the field.

APPENDIX - B

FIELD TRIAL OF ROLLER-COMPACTED CONCRETE LOCATION - PEARSON INTERNATIONAL AIRPORT DUFFERIN CONSTRUCTION CO. YARD

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Appendix C - concrete aggregate test report

project: Roller Compacted Concrete - Field Mixes		date: December 16, 1987	
aggregate: Granular "A"		file no.: 842.21	report no.: SE87-35-H
submitted by: M.F. Everitt	quantity: 5 bags	charge to: 12-105	
source: Dufferin Concrete Plant		aggregate no.'s: S-7590	
origin: Standard Aggregates, Mono Mills		October 28, 1987	

sieve analysis

	sieve size											
	mm	40	28	20	14	10	5	2.5	1.25	0.63	315	160	fm
	in./no.	1-1/2	1	3/4	1/2	3/8	no. 4	8	16	30	50	100	
combined % passing													
% passing			100	94.8	79.0	68.0	52.6	41.5	28.9	12.8	5.3	3.3	3.25
% retained			0	5.2	15.8	11.0	15.4	11.1	12.6	16.1	7.5	2.0	

	relative density			absorp %	organic no.	pass 80 um %	soundness 5 cycle loss %	petro number (PN)	abrasion	
	oven dry	sat surf dry	apparent						wear %	grading
fine aggregate	2.49	2.56	2.69	2.99	1		17.60			
coarse aggregate	2.57	2.60	2.66	1.33			16.21 (Combined) 14.64	148		

approved by

submitted by

APPENDIX D

NUCLEAR DENSITY GAUGE (TROXLER) READINGS AND COMPACTION METHOD

Compaction Method: Passes Number/Type**	Pad*	Lift*	Mix	Probe Depth (inches)	Moisture Content (%)	Dry Density (kg/m^3)	Corrected Dry Density (kg/m^3)
2 vib (8-3/4 t)	1	1	1	8	6.8	2178	2196
	1	1	1	8	6.1	2183	2187
	1	1	1	6	6.0	2217	2219
	1	1	1	2	7.0	2142	2164
	1	1	2	8	6.1	2164	2165
	1	1	2	6	6.0	2186	2184
	1	1	2	4	7.4	2115	2141
	1	1	2	2	6.1	2158	2158
	1	1	3	8	6.2	2181	2168
	1	1	3	6	6.5	2190	2185
	1	1	3	4	5.9	2218	2199
	1	1	3	2	6.4	2194	2185
Additional 1vib + 1 st (8-3/4 t)	1	1	1	8	6.6	2216	2231
	1	1	1	6	6.4	2257	2268
	1	1	1	4	6.4	2240	2250
	1	1	1	2	6.1	2238	2242
	1	1	2	8	6.3	2108	2112
	1	1	2	6	6.3	2201	2205
	1	1	2	4	6.5	2208	2216
	1	1	2	2	6.4	2173	2178
	1	1	3	8	6.2	2242	2230
	1	1	3	6	7.4	2189	2201
	1	1	3	4	7.4	2153	2164
	1	1	3	2	7.0	2161	2166
Further 4 st (8-3/4 t)	1	1	1	6	7.0	2250	2273
	1	1	2	6	6.0	2233	2230
	1	1	3	6	6.0	2236	2220
3 vib + 5 st (8-3/4 t)	1	2	1	6	6.6	2155	2170
	1	2	2	6	7.3	2136	2151
	1	2	3	6	7.5	2235	2251

* See Appendix B.

** 2 vib (8-3/4 t): two passes of 8-3/4 t vibratory roller (Make: RASCAL-900-A, 40,000 lb vibration)
1 st (8-3/4 t): one pass of 8-3/4 t static roller (Make: same as above)

Appendix D continued

Compaction Method: Passes Number/Type**	Pad*	Lift*	Mix	Probe Depth (inches)	Moisture Content (%)	Dry Density (kg/m^3)	Corrected Dry Density (kg/m^3)
Additional	1	2	1	6	7.3	2151	2178
2 st	1	2	2	6	6.6	2131	2140
(8-3/4 t)	1	2	3	6	8.4	1996	2030
No further	1	2	1	6	6.3	2169	2177
compaction	1	2	2	6	6.1	2110	2110
(16 hours later)	1	2	3	6	7.2	2233	2240
4 vib	2	1	1	6	8.0!	2195	2239
(8-3/4 t)	2	1	2	6	8.2!	2190	2233
	2	1	3	6	6.8!	2220	2220
Additional	2	1	1	6	7.6!	2240	2276
2 vib + 2 st	2	1	2	6	8.1!	2210	2251
(8-3/4 t)	2	1	3	6	6.9!	2235	2237
3 LV + 1 S	3	1	1	6	7.0!	2280	2304
(6 t)	3	1	2	6	7.3!	2220	2245
	3	1	3	6	7.2!	2210	2218
Additional	3	1	1	6	7.9!	2265	2307
2HV+2S	3	1	2	6	7.6!	2225	2256
(6 t)	3	1	3	6	8.5!	2130	2164
4 vib + 2 st	2	2	1	6	7.3!	2255	2285
(8-3/4 t)	2	2	2	6	8.1!	2230	2272
	2	2	3	6	6.7!	2225	2223
3LV+2HV+2S	3	2	1	6	7.9!	2160	2201
3LV+2HV+2S	3	2	2	6	7.5!	2215	2244
2LV+4HV+2S	3	2	3	6	6.3	2267	2256
4LV+3HV+3S	1	3	1	4	6.5	2275	2288
(6 t)	1	3	2	4	7.3	2200	2210
	1	3	3	- - - - - no readings taken - - - - -			

! Indicates moisture content and dry density readings from Trow Geotechnical

* See Appendix B

** 2 vib: Two passes of 8-3/4 t vibratory roller (RASCAL-900A, 40,000 lb vibration)

2 st: Two passes of 8-3/4 t static roller (RASCAL-900A)

3 LV: Three passes of 6 t two steel drum roller (BOMAG-BW141AD), 9383 lb vibration/drum

2 HV: Two passes of 6 t two steel drum roller (BOMAG-BW141AD), 11,858 lb vibration/drum

2 S: Two passes of 6 t two steel drum roller (BOMAG-BW141AD), 7357 lb static/drum

APPENDIX E

Moisture Content Test Results

Mix	F-1	F-2	F-3
Moisture (%) in Aggregate	6.1	6.5	6.1
Moisture (%) in Concrete	5.9	6.1	6.8

Standard Procter Test Results

Mix	F-1	F-2	F-3
Wet Density (kg/m^3)	2495	2547	2469

APPENDIX F

UNIT WEIGHT, ULTRASONIC PULSE VELOCITY (UPV) AND COMPRESSIVE STRENGTH RESULTS FOR RCC FIELD CYLINDERS (6" x 12")

RCC+ Mix	Serial Specimen No.	Date Cast	After demoulding at 24 hours		Compressive Strength and UPV			
			Density (kg/m^3)	UPV (m/s)	Age (Days)	UPV (m/s)	PSI	MPa
F-1	13867-1	Oct.28	2301*	3960	7	4010	2025	14.0
	-2	1987	2448	4175	28	4480	4245	29.3
	-3		2396	4175	28	4480	3866	26.7
	-4		2407	4235	91	4620	4070	28.1
	-5		2436	4235	91	4550	4070	28.1
	-6		2414	4235	180			
F-2	13868-1	Oct.29	2403	4235	7	4290	3000	20.7
	-2	1987	2405	4295	28	4550	3885	26.8
	-3		2404	4235	28	4550	3950	27.2
	-4		2418	4295	91	4620	4266	29.4
	-5		2366	4295	91	4620	4200	28.9
	-6		2350	4295	180			
F-3	13869-1	Oct.29	2370**	3670	7	3810	725	5.0
	-2	1987	2369	3765	28	4235	1935	13.3
	-3		2364	3720	28	4235	2040	14.1
	-4		2360	3720	91	4355	2560	17.6
	-5		2391	3720	91	4415	2978	20.5
	-6		2396	3720	180			

* Low density due to some lack of compaction
** Voids between layers noted
\+ For mix proportions, see Section 3.3 of the report

APPENDIX G

COMPRESSIVE STRENGTH RESULTS FOR GROUT* CUBES (2")

Specimen	Date Cast	Age (Days)	Compressive Strength PSI	Compressive Strength MPa	Avg. MPa
1	Oct. 29/ 1987	7	7950	54.8	
2		7	8025	55.3	53.8
3		7	7425	51.2	
4		28	9600	66.2	
5		28	9200	63.4	65.2
6		28	9550	65.8	
7		91	10930	75.3	
8		91	11080	76.4	74.9
9		91	10600	73.1	

* Mix proportions: Cement Type 10 - 720 kg
Concrete Sand - 540 kg
Water - 290 kg